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ASTRONOMY AND ASTROPHYSICS

Discovery of a giant and luminous X-ray outburst from the optically inactive galaxy pair RX J1242.6–1119*

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Abstract. We report the discovery of large-amplitude X-ray variability from the direction of the previously unknown, optically inactive galaxy pair RX J1242.6-1119. The X-ray source shows variability by a factor $\gtrsim 20$ between the *ROSAT* all-sky survey and a later pointed observation separated by ~1.5 yr. Its spectrum is extremely soft with photon index $\Gamma_x \simeq -5$, among the steepest ever observed among galaxies. Based on the redshift derived from the optical spectra, z=0.05, the source's intrinsic luminosity is large, $L_x \gtrsim 9\,10^{43}$ erg s^{-1}. Surprisingly, the optical spectra of both galaxies are characterized by absorption lines and do not show signs of (Seyfert) activity. This makes RX J1242-11 the third candidate for giant-amplitude variability in an otherwise non-active galaxy, the first two being NGC 4552 (in the UV; Renzini et al. 1995) and NGC 5905 (in X-rays; Bade et al. 1996, Komossa & Bade 1999). Several mechanisms to explain this unexpected and peculiar behavior are investigated. The most likely one seems to be an accretion event onto an otherwise dormant supermassive black hole (SMBH), e.g., by a tidal disruption event.

Key words: Accretion – Galaxies: active – Galaxies: individual: RXJ1242.6–1119 – Galaxies: nuclei – X-rays: galaxies

1. Introduction

Giant X-ray outbursts among galaxies, even the active ones, are rare. 'Normal' galaxies, starbursts, and most LINERs show constant soft X-ray emission (e.g., Fabbiano 1989, Vogler & Pietsch 1999, Komossa et al. 1999) and X-ray luminosities of typically 10^{38-40} erg s^{-1}. Some off-nuclear, X-ray-bright point sources, several of them variable, have been detected recently but they seldom exceed 10^{39} erg s^{-1} (e.g., Immler et al. 1998, Komossa & Schulz 1998, and references therein). In contrast, many active galactic nuclei (AGN; $L_x \gtrsim 10^{42}$ erg s^{-1}) are known to be X-ray variable by typically a factor 2–3 (e.g., Mushotzky et al. 1993). Outbursts with amplitudes exceeding a factor ~10-20 are very rare even among AGN, though. Therefore, it was quite surprising when giant X-ray outbursts (factors $\gtrsim$100 in countrate) from the two optically 'rather' inactive galaxies IC 3599 (Brandt et al. 1995, Grupe et al. 1995) and NGC 5905 (Bade et al. 1996, Komossa & Bade 1999) were discovered. Both outbursters were characterized by very soft X-ray spectra and reached high outburst luminosities.

The *ROSAT* all-sky survey (RASS; Voges et al. 1996) provides an excellent data base to search for further cases of giant X-ray variability. Such outbursts provide a powerful tool to probe for the existence of SMBHs in nearby galaxies and to study the physics of accretion events. In particular, Rees (1988,1989,1990) proposed to use the UV-X-ray flares expected from the tidal disruption events of stars swallowed by SMBHs to detect these SMBHs in nearby, *non-active* galaxies.

RXJ1242-11, serendipituously located in the field-of-view of a *ROSAT* PSPC pointing, was originally selected for optical follow-up observations due to its very soft X-ray spectrum in the course of the extension of the identification program of supersoft X-ray sources from the RASS (Greiner 1996) to pointed observations of nearby galaxies. We report here the optical and X-ray properties of this previously unknown source (Sect. 2) and discuss scenarios to account for its very peculiar variability behavior (Sect. 3). Luminosities given below are calculated assuming $H_0 = 50$ km/s/Mpc.

2. Data reduction and analysis

2.1. Optical observations

Spectra and images were acquired at the 1.5m Danish telescope at ESO/La Silla on January 24 and 26, 1999, equipped with DFOSC. A grism with 300 grooves per mm was used yielding a dispersion of 3.3 Å/pixel on the 2052*2052 backside illuminated LORAL/LESSER CCD. With a 1.″5 slit the FWHM resolution is 12 Å. Exposure

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* Partly based on observations obtained at the European Southern Observatory, La Silla, Chile.

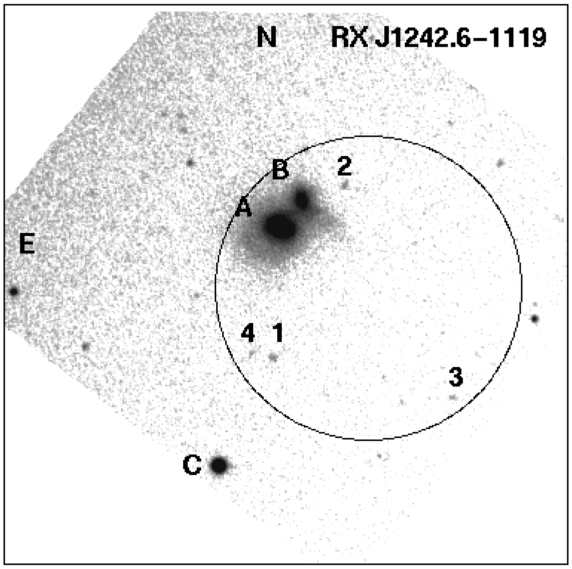

Fig. 1. A 2.′5×2.′5 V band image of the region around RX J1242.6–1119. The circle marks the X-ray position uncertainty of 40″ radius. "A" and "B" denote the galaxy pair, and numbers 1–4 mark faint objects in the error circle, sorted according to brightness: 21.8, 22.0, 22.0 and 22.4 mag, respectively (derived by comparison with USNO star U0750_07951099 which is labeled "C").

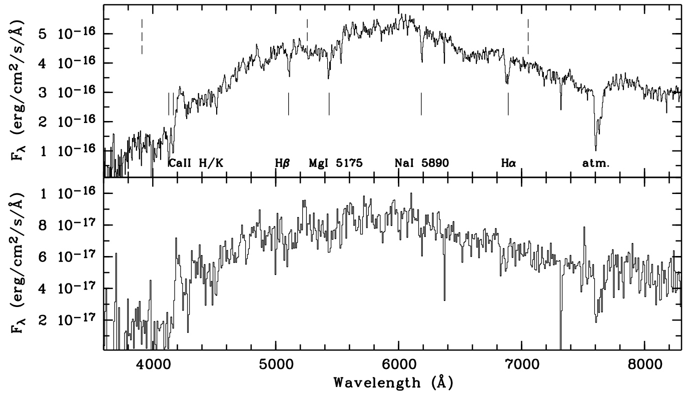

Fig. 2. Spectra of the two galaxies with the brighter one rebinned by a factor of 4 to match the bin size with the spectral resolution (top panel) and the fainter one rebinned by a factor of 8 (bottom panel). Prominent absorption lines are marked, together with the expected locations of undetected emission lines of [OII]λ3727, [OIII]λ5007 and [SII]λ6717 (dashed lines, from left to right). The feature near 4200Å which appears in both spectra is due to the improper subtraction of a large, spherical distortion in the flatfield image. The absorption near 7600Å is atmospheric in origin.

times were 900 and 2200 sec, respectively, and the spectra were debiased, flatfielded and calibrated (with the standard star GD 108) using standard MIDAS procedures.

Results: Image. The image shown in Fig. 1 is the sum of 18 acquisition images (effective exposure time of 7 min) and reveals a close pair of galaxies within the X-ray error circle. These galaxies were not resolved on the POSS, thus leading to entries in the USNO-A1.0 catalogue (Monet et al. 1998): U0750_07951028 (the optically brighter one of V=14$^{\rm m}$) and U0750_07951000 (V=16$^{\rm m}$). They are probably interacting, as indicated by a 'light bridge' between the two. Further objects visible in the image are fainter than V=21.8 mag. The optical coordinates (J2000) of the two galaxies are α=12$^{\rm h}$42$^{\rm m}$38.$^{\rm s}$5, δ=–11°19′21″(U0750_07951028) and α=12$^{\rm h}$42$^{\rm m}$38.$^{\rm s}$2, δ=–11°19′15″(U0750_07951000).

Results: Spectra. The optical spectrum of the brighter of the two galaxies is characterized by strong absorption lines of Na I 5175Å, Mg I 5890Å and Hβ (Fig. 2; note that Hα overlaps with the atmospheric B band). Using the Mg I and Na I line we derive a redshift of z = 0.050 ± 0.001. The slope of the spectrum suggests either an elliptical or early spiral type. The Balmer absorption lines indicate the presence of A stars. Both, these deep Balmer lines as well as the strong drop of the flux beyond the Ca II H/K break argue against a classification as BL Lac object. No AGN-like forbidden emission lines, like [OIII]λ5007, are detected.

The spectrum of the second, optically weaker galaxy looks very similar to the first one (Fig. 2, lower panel). Using the same absorption lines as above, we derive the same redshift of z = 0.05. Although, again, this spectrum is not like those of AGN, we note that there appears to be some excess emission close to the location of the [OIII]λ5007 line.

2.2. X-ray observations

The region of RX J1242-11 was observed twice with the *ROSAT* (Trümper 1983, Briel et al. 1994) PSPC. First in December 1990 – January 1991 during the RASS, then serendipituously in a pointed observation of July 1992 where RX J1242-11 is located 40′ off-axis. Details of the observations are given in Table 1. The data reduction was carried out in a standard manner. In brief, for the spectral and temporal analysis of the PSPC pointed data source photons were extracted within a circular region of radius 400″ centered on the target source. The background was determined in a source-free ring around the target source and subtracted. The data were corrected for vignetting using the EXSAS software package (Zimmermann et al. 1994). To carry out the spectral analysis source photons in the amplitude channels 11-240 were binned according to a constant signal/noise ratio of 5σ.

Table 1. Log of the X-ray observations and results from spectral fits. $t_{\rm exp}$ gives the exposure time, CR the countrate in the (0.1-2.4) keV band. $\Gamma_{\rm x}$ is the photon index derived from the powerlaw spectral fit, kT the black body temperature for the black body fit (see text for details). In both cases, we fixed $N_{\rm H} = N_{\rm Gal}$. Errors in $\Gamma_{\rm x}$ and kT are quoted at 68% confidence. $L_{\rm x}$ gives the intrinsic luminosity in the (0.1–2.4) keV band.

observ.	date	$t_{\rm exp}$ sec	CR cts/s	X-ray coor. (J2000) RA	DEC	$\Gamma_{\rm x}$	$L_{\rm x,pl}$ 10^{43} erg/s	$kT_{\rm bb}$ keV	$L_{\rm x,bb}$ 10^{43} erg/s
RASS	28-29/12/90 + 17/1/91	270	<0.015						
point.*	15-19/7/92	10567	0.3	$12^{\rm h}42^{\rm m}36\overset{\rm s}{.}9$	$-11°19'35''$	-5.1 ± 0.9	35.5	0.06 ± 0.01	8.8

* Observation identification number 600258p

2.2.1. Temporal analysis

Whereas RX J1242-11 is *brighter* in X-rays than the galaxy on which the pointing was centered, M 104, RX J1242-11 is *not detected at all* during the RASS. In contrast, M 104 is again clearly detected. This immediately reveals large-amplitude variability of RX J1242-11.

We estimate a 3σ upper limit countrate of 0.015 cts/s during the RASS observation. In the pointed observation, the source is partially hidden behind the detector support rib structure. Not correcting for the partial shadowing effect, we derive a mean source countrate of 0.125 ± 0.005 cts/s. Following the variation of the source's countrate over the wobble paths, the countrate reaches maximal values of 0.3 cts/s and we take this as the best estimate for the undisturbed source emission. Comparison with the countrate upper limit derived for the RASS observation reveals variability by a factor larger than 20.

2.2.2. Spectral analysis

Several spectral models were fit to the X-ray emission, starting with a powerlaw and cold absorption fixed to the Galactic value in direction of RXJ1242-11, $N_{\rm Gal} = 3.74\,10^{20}$ cm^{-2} (Dickey & Lockman 1990). We find $\Gamma_{\rm x} = -5.1 \pm 0.9$ ($\chi^2_{\rm red} = 1.5$). No source photons are detected above $\sim$1 KeV. Treating $N_{\rm H}$ as free parameter, the powerlaw becomes even steeper ($\Gamma_{\rm x} \simeq -9$ and $N_{\rm H} \simeq 3\,N_{\rm Gal}$, but both parameters are no longer well constrained). Alternatively, a black body was fit. This yields $kT_{\rm bb} = 0.06\pm0.01$ keV for $N_{\rm H} = N_{\rm Gal}$ and gives an excellent fit ($\chi^2_{\rm red} = 0.7$). We repeated all spectral fits using a second background region and find the same best-fit parameters within the errors. Results are summarized in Table 1.

Using the powerlaw (black body) fit and $N_{\rm H} = N_{\rm Gal}$, we derive an intrinsic X-ray luminosity of $L_{\rm x} = 35.5\,(8.8) \times 10^{43}$ erg s^{-1}. This is a lower limit on the actual peak luminosity emitted during outburst, since we most likely have not caught the source exactly at maximum light, since the spectrum may extend into the EUV, and since there may be excess absorption along the line-of-sight. Each of the three effects could easily boost $L_{\rm x}$ by an order of magnitude.

3. Discussion

In summary, the properties to be explained by any outburst model are: (i) high outburst luminosity, (ii) very soft X-ray spectrum, and (iii) optical spectrum of a non-active galaxy. Below, we briefly compare with the few other cases of UV-X-ray variability among non-active galaxies reported so far, and then discuss possible scenarios for RX J1242-11.

3.1. Previous observations of large-amplitude X-ray outbursts in optically non-active galaxies

IC 3599 (Brandt et al. 1995, Grupe et al. 1995) and NGC 5905 (Bade et al. 1996) both underwent giant X-ray outbursts. The optical spectrum of IC 3599 shows several indications of activity even in X-ray quiescence (Komossa & Bade 1999; KoBa99 hereafter) which is not the case for NGC 5905. Its spectrum is that of an HII galaxy. Many outburst models were studied, and tidal disruption of a star by a SMBH (e.g., Rees 1988, 1990; Loeb & Ulmer 1997) was tentatively favored as explanation. Another strongly X-ray variable source, with an optical spectrum quite similar to RX J1242-11 will be presented by Grupe et al. (A&A, subm). It is also worthwhile to mention NGC 3628 which showed a *drop* by a factor 20 in *ROSAT* flux (Dahlem et al. 1995). In the UV spectral region, an outburst was detected from the elliptical galaxy NGC 4552, interpreted by Renzini et al. (1995) as accretion event (the tidal stripping of a star's atmosphere by a SMBH, or the accretion of a molecular cloud).

3.2. Variability mechanisms

In the discussion below, we assume that indeed an outburst occurred, instead of a transient drop in luminosity. Whereas the outburst character was well evidenced by the long-term X-ray lightcurve of NGC 5905 (cf. Fig. 9 of KoBa99), we only have two measurements for RXJ1242-11 so far, one in low-state, one in high-state. Besides the analogy to the previous outbursting sources a further argument in favor of an outburst is that the continuous X-ray emission of 'normal' galaxies usually does not exceed 10^{39-41} erg s^{-1} and is extended.

Further, we note that the presence of a Galactic foreground object is unlikely, since further optical sources within the X-ray error circle are extremely weak, and RXJ 1242-11 is at high Galactic latitude (b_{II}=51°.5). Given the high L_X/L_{opt} value, an ISM accreting neutron star might come to mind, but the strong X-ray variability would require an extreme ISM density gradient, thus leading us to reject this possibility.

Many outburst scenarios were already discussed for the case of NGC 5905 (KoBa99). Several (variable stellar sources, like X-ray binaries, supernovae (SN), or SN in dense medium) turned out to be very unlikely since they cannot fulfill the tight constraint set by the huge outburst luminosity. This similarly holds for RX J1242-11. Further models (for details see the estimates and references in KoBa99) are discussed in turn:

Could we have witnessed the X-ray afterglow of a GRB ? This is unlikely, since the "on" timescale of several days is much too long as compared to all known cases of GRB afterglows (e.g., Greiner et al. 1999), which quickly faded with a t^{-1} law after detection.

The presence of a hidden Seyfert nucleus obscured by a *dusty* warm absorber is in conflict with the very steep observed X-ray spectrum.

Remaining scenarios link the activity to accretion onto a central SMBH in one of the two galaxies:

(i) Accretion disk instability: If an accretion disk is present in the system, the accretion rate would have to be rather low, since there is no multi-wavelength evidence for an AGN. The disk may then settle into the advection dominated (ADAF) mode. Whereas ADAFs in general would be characterized by a larger extent of the X-ray emitting region as compared to AGN, implying less variability than usual (e.g., Ptak et al. 1998), a localized instability in such a disk could still produce an outburst. Also, the disk would be more compact in a Kerr metric.

The thermal instability of slim accretion disks was studied by, e.g., Honma et al. (1991). They find the disk to exhibit burst-like oscillations for the case of the standard α viscosity description and for certain values of accretion rate. However, in case of repeated such outbursts in RX J1242-11, one might still expect to see permanent AGN-typical NLR emission lines (like [OII], [OIII], and [SII]) in the optical spectrum of this galaxy (in contrast to emission from what is known as the BLR in Seyferts; these clouds would have much higher densities than the NLR and a correspondingly lower recombination timescale.)

(ii) Tidal disruption of a star: Depending on its trajectory, a star gets tidally disrupted after passing a certain distance to the black hole, the tidal radius, and the debris is accreted by the hole. This produces a flare of electromagnetic radiation, lasting on the order of months (Rees 1988, 1990). The peak luminosity should be a substantial fraction of the Eddington luminosity. Rees pointed out that these flares would be excellent indicators of the presence of SMBHs in nearby, *non-active* galaxies. The X-ray outburst of RX J1242-11 might have originated from such a tidal disruption event. We can then roughly estimate a lower limit on the SMBH mass in RXJ 1242-11 via the Eddington luminosity which leads to $M_{\rm BH} \gtrsim 7\,10^5$ $M_\odot$ if we use our conservative lower limit on the outburst luminosity. More detailed comparisons, e.g., in terms of spectral fits based on this scenario would have to await more sophisticated model calculations. In particular, the flares cannot be standardised and observations will depend on many parameters, like the type of disrupted star, the impact parameter, the spin of the black hole, effects of relativistic precession, and the radiative transfer is complicated by effects of viscosity and shocks (Rees 1990).

(iii) A more speculative scenario would link the outburst to some merger-induced onset of fuelling of the central region (e.g, Mihos, 1999). There are clear signs that the galaxy pair is interacting[1]. Athough their distance is presently quite large (about 15 kpc), they may have already had a closer encounter and the velocity field in the central region might be disturbed, favoring accretion events onto the SMBH.

Follow-up X-ray observations, and long-term monitoring if the source turns out to be still "on" would provide valuable further clues on the nature of this peculiar source.

4. Summarizing conclusions

We have reported the detection of a giant X-ray outburst from the previously unknown galaxy pair RX J1242.6-1119. The outburst X-ray spectrum is very soft (photon index $\Gamma_x \simeq -5$) and luminous ($L_x > 9\,10^{43}$ erg s^{-1}), whereas the optical spectra of both galaxies do not show evidence for Seyfert activity. We therefore suggest that RX J1242-11 is another of the rare cases of giant UV/X-ray outbursts from non-active galaxies. The X-ray variability is most likely linked to an accretion event – e.g., by the tidal disruption of a star as predicted by Rees (1988) – on a SMBH residing in the center of one of the two galaxies.

Such X-ray outbursts thus provide important information on the presence of SMBHs in non-active galaxies, the accretion history of the universe, and the link between active and normal galaxies. Further exploitation of the *ROSAT* data base and future X-ray surveys (like the one that was planned with *ABRIXAS*) will be very valuable in finding further of these outstanding sources.

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[1] Since many mergers are known to be IR-luminous, we checked the IRAS faint source catalogue. The two galaxies are not listed as IR sources, though.

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